Hydrology & Hydraulics Support for the Rodeo-Chediski Fire in Arizona 2002

Michael A. Hrzic[1] and Kerry Casey[2]

[1]Hydraulic Engineer, CESPL-ED-HH, (213) 452-3567, michael.a.hrzic@.usace.army.mil
[2]Hydraulic Engineer, CESPL-ED-HH, (213) 452-3574, kerry.t.casey@.usace.army.mil

Introduction

In July of 2002, the Rodeo and Chediski Fires began as separate fires along the Mogollon Rim, in eastern Arizona. The two fires eventually combined to form the Rodeo-Chediski Fire, in which almost 500,000 acres were impacted. Much of that area was severely or moderately burned. During the aftermath, there was concern that the impacts due to the fire would increase runoff, which in turn, may increase the probability of flooding along the washes and creeks flowing through the burned area. In addition, there was concern the increase in sediment and debris inflow to Black canyon Reservoir, may impact the integrity of the structure. In support, the U.S. Army Corps of Engineers, Los Angeles District (LAD) developed discharges for the 100-, 10- and 2-year events in the Black Canyon Wash Watershed to evaluate the impact of the fires. The results were applied to assess the impact of the fire for the Black Canyon Watershed and incorporated into a dam failure analysis for Black Canyon Dam.

The Black Canyon Watershed is located in eastern Arizona within the Little Colorado Watershed; see Figures 1 and 2. The drainage area at the city of Heber is 69.2 mi^2, which includes Black Canyon Wash and Buckskin Wash. The drainage area for Black Canyon Wash at Black Canyon Dam is 5.85 mi^2 and at Heber is 40.06 mi^2. The drainage area for Buckskin Wash at Heber is 29.14 mi^2. The drainage area of Black Canyon Wash at the burn boundary is approximately 36 mi^2 or 90% of the watershed. The drainage area of Buckskin Wash at the burn boundary is approximately 28 mi^2 or 96% of the Buckskin Wash Watershed.

Black Canyon Dam is a relatively small earthen dam used primarily for recreation. The top of dam is at elevation 7073.7 ft. The dam crest length is 420 ft, the crest width is 24 ft, and the dam height is 68 ft. The spillway crest is at elevation 7065.7 ft and the spillway crest length is 40 ft. The reservoir storage at spillway crest is 1581 acre-ft. The storage at top of dam is 1,901 acre-ft. The contributing drainage area at Black Canyon Dam (5.85 mi^2) represents only 15% of the total drainage area for Black Canyon Wash at Heber (40.06 mi^2) and only 8% of the total drainage area (69.2 mi^2) at Heber. Black Canyon Dam provides incidental flood control, depending on the current water surface elevation and is only effective for a short distance from the dam. The impact on peak flow reduction at the City of Heber is minimal.

Discharge-Frequency Analysis

The no-burn condition discharges were estimated using regression equations developed by the USGS and published in the "Nationwide Summary of U.S. Geological Survey Regional Regression Equations For Estimating Magnitude and Frequency of Floods for Ungaged Sites, 1993". Black Canyon Watershed is located within Region 3. The area has an average watershed elevation of 7,100 ft and an average annual precipitation of 20 inches. The relationships used to estimate the 100-, 10-, and 2-year discharges are:

$$n = 100 \qquad Q_n = 553 DA_i^{0.61} ELEV^{-1.3} \operatorname{Pr} ecip^{0.915}$$

$$n = 10 \qquad Q_n = 74.7 DA_i^{0.638} ELEV^{-1.0} \operatorname{Pr} ecip^{0.971}$$

$$n = 2 \qquad Q_n = 5.66 DA_i^{0.673} ELEV^{-0.605} \operatorname{Pr} ecip^{1.03}$$

where: Qn = discharge in ft^3/s,
DA = drainage area in mi^2,
ELEV = average watershed elevation, in thousands of feet, and
Precip = average annual precipitation, in inches.

A summary of the frequency discharges for the no-burn conditions is shown in Table 1.

Table 1: Summary of Discharge-Frequency Results

Location	Drainage Area (mi^2)	100-Year (ft^3/s)	10-Year (ft^3/s)	2-Year (ft^3/s)
Black Canyon Wash at Heber	69.2	8,890	2,880	660
Black Canyon Wash at Black Canyon Dam	5.85	1,970	600	120

The impacts associated with burn conditions were estimated using a set of regional discharge-frequency equations for tributaries of the Salt River adjusted to take into account the effect of the Rodeo-Chediski Fire, developed by LAD. The Salt River Watershed is located South of the Black Canyon Watershed on the southern portion of the Mogollon Plateau; the Black Canyon Watershed lies on the northern portion of the plateau. The original set of regression equations were developed to estimate the peak discharge-frequency values for tributaries within the Salt River Wastershed. Hydrographs for both the 100- and 10-year events were simulated using the HEC-1 rainfall-runoff model calibrated to peak discharge estimates.

To estimate the effect of the burn condition within the study area, the HEC-1 rainfall-runoff models were modified to take into account the burn conditions as reported by the Burn Area Emergency Rehabilitation (BAER), see Ref. A. The BAER Team estimated SCS curve numbers (CN) associated with burn conditions for the entire Rodeo-Chediski fire area. The change in CN averaged about 30% for the fire area (pre-burn CN was 67, post-burn CN ranged from 68 to 92). Since the Corps HEC-1 rainfall runoff models of Salt River Basin did not use the SCS CN runoff transform method, an adjustment in percent impervious cover (PIC) was used to reflect the change in watershed runoff response under burned conditions. The runoff response from the 30% CN increase was determined to be equivalent to an increase in percent impervious cover (PIC) averaging about 18%. This was used to represent the conditions for a 100% burn. The PIC was adjusted in the HEC-1 models to simulate the burn conditions. The frequency discharges from the 100%-burn conditions were plotted versus discharges from the no-burn condition and regression equations were developed. Since the drainage area for the area upstream from the City of Heber was almost completely burned and since the basin characteristics for a burn condition are similar to those of the Salt River Basin, it was deemed applicable to adopt the equations developed for 100%-burn conditions for the Black Canyon Watershed.

The equation for the 100-year discharge for 100%-burn conditions is:

$$Q_{b100} = 1.4708\ Q_{100}^{\ 1.0044}$$

where: Q_{b100} = 100-year burn condition discharge
Q_{100} = 100-year no-burn discharge.

Similar equations were developed for the 10- and 2-year discharges under burn conditions and are shown below:

$$Q_{b10} = 0.4542\ Q_{10}^{\ 1.1821}$$

where: Q_{b10} = 10-year burn condition discharge
Q_{10} = 10-year no-burn discharge,

and,

$$Q_{b2} = 1.0785\ Q_{2}^{\ 1.0785}$$

where: Q_{b2} = 2-year burn condition discharge
Q_{2} = 2-year no-burn discharge.

. A summary of discharges for no-burn and burn conditions for the area draining into Black Canyon Dam and at the City of Heber are shown in Table 2.

Table 2:Summary of Frequency Discharges

Condition	Location	D.A. (mi^2)	100-Yr (ft^3/s)	10-Yr (ft^3/s)	2-Yr (ft^3/s)
No-Burn	at Heber	69.2	8,890	2,880	660
100%-Burn	at Heber	69.2	13,600	5,580	1,970
No-Burn	at Black Canyon Dam	5.85	1,970	600	120
100%-Burn	at Black Canyon Dam	5.85	3,000	870	330

The frequency discharges shown in Table 2 do not include a "bulking" factor to account for the additional sediment and debris attributed to the recentness of the fire. The discharges represent an "average" condition for the watershed reflecting the past burn and no-burn conditions. It is expected the current burn conditions in the Black Canyon Watershed will translate into an additional volume of sediment and debris being transported during runoff events. The BAER Team assumed a bulking of factor of 25% when estimating the impact of sediment and debris in the "Rodeo-Chediski Fire Watershed Technical Report" dated July 2002. The actual increase is dependent on the time since burn, yield, transport capacity, slope, blockage, rainfall intensity, and other factors. The work for this analysis does not include any attempt to quantify the additional bulking factor attributed to the fire.

Rainfall Runoff Model

To determine the peak discharge associated with a dam failure, hydrologic rainfall-runoff models were developed using the HEC-1 computer model. The 100-, 10-, and 2-year events for no-burn and burn conditions, along with a dam failure at Black Canyon Dam, were simulated. Subarea information for Black Canyon Wash and Buckskin Wash was developed using existing USGS Quad Maps with a 20-foot contour interval, 30-meter USGS Digital Elevation Models (DEMs), and local field survey information

The precipitation time series pattern used in the HEC-1 models for all simulations was based on the 1970 storm near Flagstaff, AZ. This pattern was also used in the Salt River Basin analysis by LAD. The 24-hour point precipitation values for the 100-, 10-, and 2-year events were determined from NOAA Atlas II for Arizona and are 6.53, 4.22, and 2.37 inches, respectively. The 6-hour point precipitation values area 4.47, 2.92, and 1.68 inches, respectively. Since the models were calibrated by adjusting the hydrograph ordinates as described below, it was unnecessary to areally reduce the precipitation used in the models.

The Muskingum-Cunge routing method was used for both Black Canyon and Buckskin Washes. Eight-point cross sections were used in the HEC-1 models. The cross sections were taken every 3000-4000 feet for the upstream canyon areas using the 30-meter DEMs. Cross sections for the area along Black Canyon Wash in and immediately upstream from the city of Heber were based on field survey information and were taken every 1000-2000 feet. The cross sections taken from the DEMs needed to be manually adjusted so the channel elevations and overbank elevations were consistent. These cross sections were plotted using Excel and modified.

HEC-1 models were developed for the entire watershed draining to the City of Heber. Each HEC-1 model was calibrated to the corresponding peak discharge for the 100-, 10-, and 2-year frequencies for the no-burn and burn conditions. Calibration was done using a ratio of the hydrograph ordinates for each subarea. The ratios were adjusted until the downstream discharge closely matched the frequency discharges for both no-burn and burn conditions. Black Canyon Dam was not included in the calibration runs since the impact on peak discharge at Heber is minimal.

Once the models were calibrated, the data for Black Canyon Dam was inserted. Three initial scenarios were evaluated for no-burn conditions. The results are shown in Table 3 below.

Scenario A: The 100-year peak discharge event, with no-burn conditions and spillway not blocked. The starting water surface elevation in the reservoir was 7055.7 ft (the current water surface elevation as observed on a recent visit to the site).

Scenario B: The 100-year peak discharge event, with burn conditions and spillway not blocked. The starting water surface elevation in the reservoir was 7055.7 ft (the current water surface elevation as observed on a recent visit to the site).

Scenario C: The 100-year peak discharge event, with no-burn conditions and spillway not blocked. The starting water surface elevation in the reservoir was 7065.7 ft.

Table 3: Results For Scenarios A through C

Scenario	Max. Water Surface Elevation (ft)	Peak Inflow (ft^3/s)	Peak Outflow (ft^3/s)	Max. Storage (acre-feet)	Peak Discharge at Heber (ft^3/s)
A	7058.85	2,190	0	1,130	9,000
B	7061.91	2,990	0	1,330	13,600
C	7068.76	2,190	660	1,700	9,040

Dam Failure Scenarios

Earthen dams do not tend to completely fail, nor do they fail instantaneously. Once a developing breach has been initiated, the discharging water will erode the breach until either the reservoir water is depleted or the breach resists further erosion. The dam breach parameters used in this analysis were based on the recommendations made in the publication from the U.S. Army Corps of Engineers, Hydrologic Engineering Center, “Flood Emergency Plans, Guidelines for Corps Dams”, dated June 1980. For earthen dams the breach width should be ½ to 3 times the dam height. The side slope of the breach should be in the range of 0:1 to 1:1, and the failure time should range from ½ to 4 hours. For Black Canyon Dam the parameters chosen are:

Elevation of bottom of breach (when breach is at maximum)	=	7005.7 ft
Width at bottom of breach (when breach is at maximum)	=	50 ft
Side slopes of breach	=	1:1
Failure time	=	1 hour
Elevation of water surface (that causes failure)	=	7073.8 ft

To assess the significance of a dam failure, five different scenarios were evaluated.

Scenario D: The 100-year peak discharge event, with burn conditions and spillway not blocked. The starting water surface elevation in the reservoir was 7065.7 ft (spillway crest).

Scenario E: The 100-year peak discharge event, with burn conditions and spillway blocked. The starting water surface elevation in the reservoir was 7065.7 ft (spillway crest).

Scenario F: The 100-year peak discharge event, with burn conditions and spillway blocked. The starting water surface elevation in the reservoir was 7072.0 ft. This scenario was created to simulate dam failure occurring at the time of peak inflow at the dam to generate the highest discharge at Heber.

Scenario G: The 100-year peak discharge event, with burn conditions and spillway blocked. The starting water surface elevation in the reservoir was 7073.7 ft (top of dam).

Scenario H: The 100-year peak discharge event, with burn conditions, spillway blocked, and no other runoff contributing to Black Canyon Wash downstream of the dam. The starting water surface elevation in the reservoir was 7073.7 ft (top of dam).

Results from Hydrologic Modeling. The peak discharges at Heber for the five dam failure scenarios are shown on Table 4.

Table 4: Results For Dam Break Scenarios at Black Canyon Dam

Scenario	Max. Water Surface Elevation (ft)	Peak Inflow (ft^3/s)	Peak Outflow (ft^3/s)	Max. Storage (acre-feet)	Peak Discharge at Heber (ft^3/s)
D	7070.06	2,990	1,130	1,760	13,800
E	7073.81	2,990	47,100	1,930	19,900
F	7073.94	2,990	50,000	1,970	33,000
G	7073.80	2,990	47,000	1,930	18,200
H	7073.90	3,000	50,600	1,960	21,100

The 100-year discharge at Heber increases by about 50% when changing from the no-burn condition to the burn condition (Scenario A to B). However, there is no outflow from Black Canyon Dam under either of these two scenarios.

Scenario C. If the starting water surface elevation is set at the current reservoir elevation (7055.7 ft.), there is sufficient storage available behind the dam to capture the runoff generated during a 100-year event, under burn or no-burn conditions. The maximum water surface elevation does not exceed 7065.7 ft and no outflow occurs. The dam will not overtop and no breach occurs.

The dam will not overtop during a 100-year event under burn conditions if the spillway does not get blocked (Scenario D). The maximum spillway flow is 1,130 ft^3/s. The difference in peak discharge at Heber is insignificant

For Scenario E, the volume of the 100-year inflow hydrograph (410 ac-ft) exceeds the storage available between spillway crest and top of dam (320 ac-ft); thus the dam is overtopped and a dam failure is assumed. The peak outflow is 47,100 ft^3/s, but the outflow routes down quickly and the increase in peak discharge at Heber is only 6,300 ft^3/s.

Under Scenario F, the start of dam failure was set to coincide with the peak inflow from the 100-year event at the reservoir. This produces the highest dam failure peak discharge (50,000 ft^3/s) and volume and results in the highest peak discharge at Heber; 33,000 ft^3/s. The travel time for the peak discharge to reach Heber from the time of the dam failure was estimated to be 1.25 hours.

For Scenario G, the starting water surface elevation is set at the spillway crest elevation of 7073.7 ft. The dam is overtopped immediately and a breach is assumed. The maximum outflow is 47,000 ft^3/s and the peak flow at Heber is 18,200 ft^3/s. The maximum values shown in the table are slightly less than Scenario D because of timing of the inflow hydrograph and the time of failure.

Lastly, under Scenario H, the starting water surface elevation is set at the spillway crest elevation of 7073.7 ft. The storm is centered above the dam and no additional inflow is included downstream from the dam. (The 100-year inflow for a storm centered above the dam was based on a three-hour thunderstorm precipitation pattern so the results differ slightly.) Dam failure occurs immediately. The peak outflow is 50,600 ft^3/s and the peak discharge at Heber is 21,100 ft^3/s.

Summary

It is well known that fires have a significant affect on the infiltration rates and runoff from a watershed. In the case of the Black Canyon Watershed at Heber, AZ., the simulated burn condition increased runoff for the 2, 10 and 100-year events by 3.0, 1.9 and 1.5 times, respectively, compared to results from the simulated no-burn condition.

In addition to increasing the watershed runoff, fires also increase the debris yield and thus, the potential of dam failures. The results of the Black Canyon Dam Break analysis show that under a scenario where the dam failure coincided with the peak discharge from the 100-year event at the reservoir, the resulting discharge at Heber was 2.4 times that of the 100-year discharge under no-burn condition at Heber.

Fire's effect on runoff presents a difficult challenge for estimating the resulting runoff under the burn condition. As shown here the result can be sizeable for infrequent events and can also cause problems associated to dams and other structures within the river.

References

a) Informal Correspondence: field data for Carrizo Creek, Cibecue Creek and Corduroy Creek, from BAER Support Team (Burn Area Emergency Rehabilitation), dated 12 July 2002, - Estimated SCS Curve Numbers representative of site visit assessment.
b) Technical Report, "City of Heber, AZ. Hydrologic and Hydraulic Analysis Impact of Rodeo Chediski Fire", U.S. Army Corps of Engineers, Los Angeles District, Hydraulics and Hydrology Branch, September 2002.
c) Technical Memorandum "Impact of Burn on Watersheds Tributary to the Salt River", U.S. Army Corps of Engineers, Los Angeles District, Hydraulics and Hydrology Branch, March 2003.

Figure1. Location Map
Heber, AZ

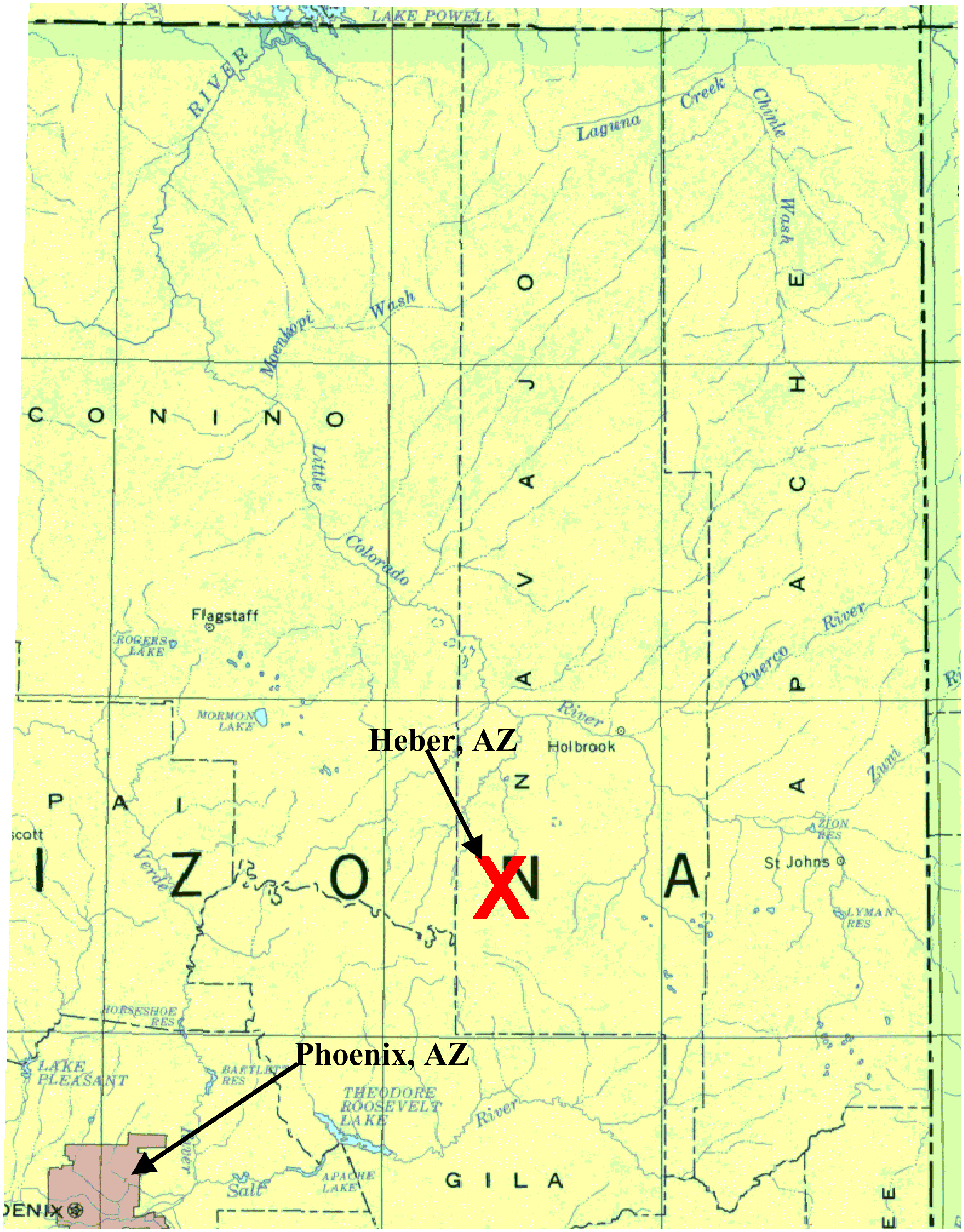

Figure2. Area Map
Heber, AZ